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PERIODICITIES IN THE SOLAR-CONSTANT MEASURES

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PERIODICITIES IN THE SOLAR-CONSTANT MEASURES

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INTRODUCTION

This paper, based on over 40 years of observations of solar radiation, ties together the following conclusions:

1. The sun's output of radiation varies.
2. It varies in at least 23 regular periodicities, all proceeding simultaneously.
3. The periods of solar variation are integral submultiples of 22¾ years.
4. Synthesis of curves representing the 23 periodicities reproduces the original observations of the "solar constant" to within about 0.1 percent.
5. Synthesis of these curves for 12 years as a prediction, prior to the observations on which they depend, shows rough agreement with Mount Wilson observations of the solar constant, in the years 1908 to 1920.
6. A much more satisfactory agreement is found between this predicted synthetic solar-constant curve and the Mount Wilson determinations of the march of contrast along the east-west diameter of the sun, of 1913 to 1920.
7. Higher contrast attends higher solar-constant values.

In several former publications[2] I have discussed the periodic changes in observed values of the solar constant of radiation.

For several years I have been investigating the effect on terrestrial weather of these periodic changes in the sun's emission. I had become convinced by the earlier solar-constant studies, just cited, that the sun's radiation varies simultaneously in many regular periods, all

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[1] I wish to express my sincere acknowledgments to L. B. Aldrich, Director of the Astrophysical Observatory, who made the data available for this paper and gave highly valuable criticisms; to Frederick E. Fowle, deceased, whose careful measurements of solar contrast appear in table 6; to Mrs. A. M. Bond, deceased, whose critical judgment and accurate computations aided in the preparation of the data; to the many observers on high mountains in distant lands who sacrificially kept up this long campaign of measurement; to Mrs. I. W. Windom, who assisted in preparing this text; and to Miss M. A. Neill, who continuously over many years greatly assisted me in keeping the observing stations in operation.

[2] Annals Astrophys. Obs., Smithsonian Inst., vol. 5, p. 250 et seq., 1932; vol. 6, p. 178 et seq., 1942. Smithsonian Misc. Coll., vol. 111, No. 7, 1949.

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aliquot parts of $22\frac{3}{4}$ years. I hoped, by using a long interval of scores of years of an unbroken series of monthly weather records, that I could discover from them all the submultiples of $22\frac{3}{4}$ years which yield effective periodic variations of the solar radiation.

But I found that the variations of the atmospheric conditions from time to time, some associated with the seasons and some with the sunspot cycle, so badly confuse the phases of responses to solar variation that I could not be certain that all the suspected solar periodicities, inferred from weather records, are real. Hence I felt constrained to reinvestigate the observed fluctuations of the solar constant, to determine directly which of the submultiples of $22\frac{3}{4}$ years are truly periods in solar variation.

In former papers I have used 273 months as the master period, of which the others are integral submultiples. My present work leads me to prefer 272 months. All the periods which I have found lie within less than 1 percent of being integral fractions of 272 months.

ADVANTAGES OF METHOD

Some investigators would prefer to submit the available solar-constant data to a Fourier analysis based on 272 months. I prefer to tabulate the data according to each suspected possible period. There are several advantages in this method. In so doing, I divide the total interval covered by the data into several parts, if periods are short enough to furnish a large number of repetitions. In this way the phases of features may be compared in the several independent tabulations of one period. Graphs showing this procedure are given in figure 1. Slight shifts,[3] from one to another of the successive tabulations, indicate small corrections to the assumed period. The form of the curve of fluctuation is determined by the tabulations. Also the amplitude of the periodic variation is found. If it is too small to be certainly exceeding the probable error, then the periodicity is to be rejected altogether. Proceeding in this way, I found 23 periodicities in solar-constant results which meet the tests of veridity just indicated. Fifteen other periods were tabulated, but rejected. Each search involved tabulating more than a thousand decade mean values of the solar constant. The results appear in table 1.[4]

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[3] See the curves, 6 1/30, of figure 1, in comparison with table 1C, below.

[4] In tabulating any one periodicity, all the others exercise confusing influences, which are not wholly eliminated, because of the small numbers of repetitive columns going to make up the tables. Hence, irregularities in the curves of figure 1 are caused by conflicting periodicities, in addition to the effects of accidental errors of observation.

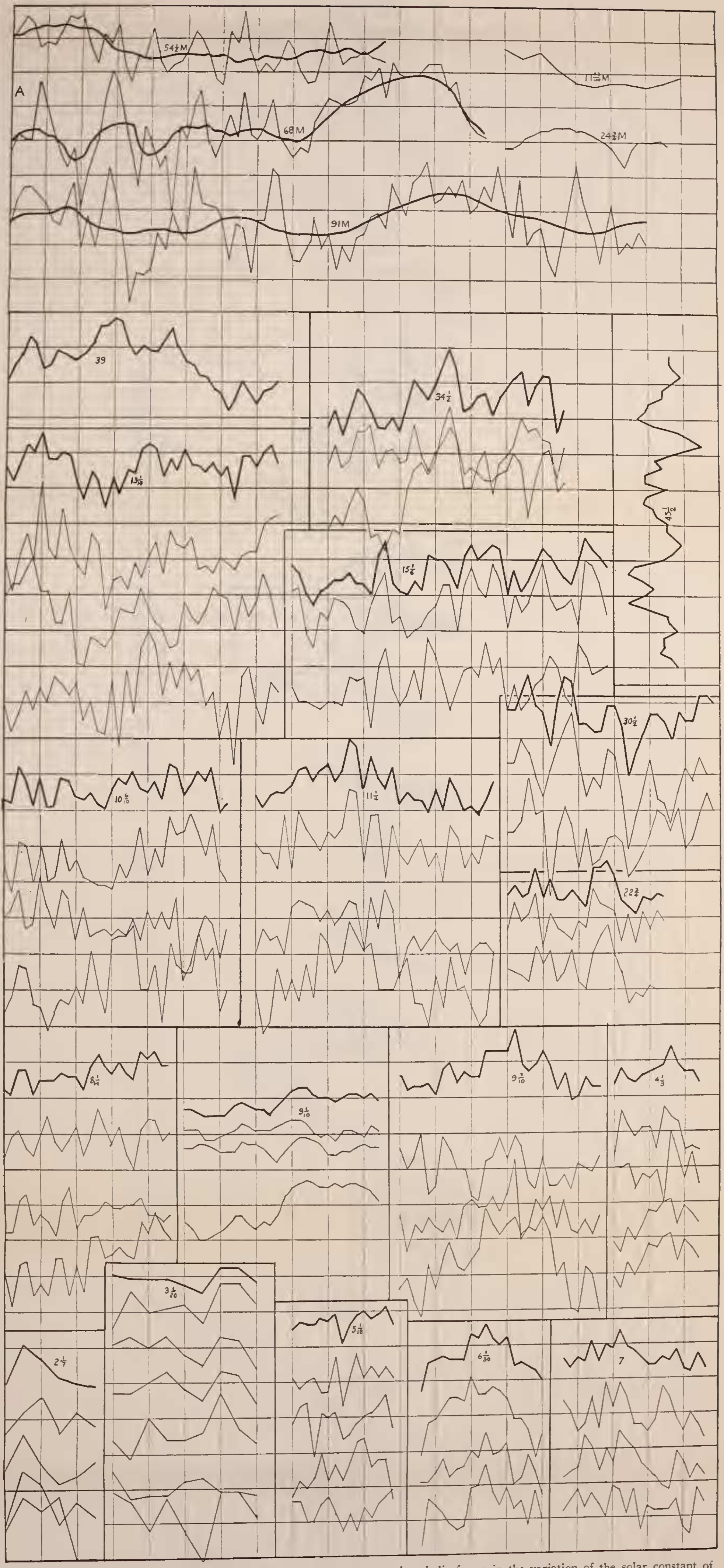

Fig. 1.—Consecutive partial determinations and general means of periodic forms in the variation of the solar constant of radiation as observed 1920 to 1950. Periods are indicated in months. Spaces in ordinates represent 1/10 percent variation in solar radiation.

It may aid to fix ideas on the method of tabulation to give an example. Table 1C is a facsimile of the computation for the period 6 1/30 months. I select it as indicating how fractional parts of months and of 10-day means are treated, so as to preserve the exact average period. I had at first assumed that 6 1/15 months was the proper length of period. The data were separated into three groups. The assumed period corresponds with 18 1/5 10-day intervals. When the mean values for the three groups were computed, they were plotted, superposed. It was then apparent that the maximum ordinates shifted progressively toward earlier dates, as time went on. This indicated that the assumed period is too long by 4/700 of itself. Making this correction, the true period is 6 1/30 months.

PREPARATION OF DATA

L. B. Aldrich, Director of the Astrophysical Observatory, and his associates had painstakingly considered every circumstance affecting every daily solar-constant observation, at all the Smithsonian mountain stations in various lands. By consensus of three individual opinions, they had assigned to every observed day its most probable solar-constant value, as indicated by the checked results of all stations. Many days were not observed at all. However, there was no decade of any month, from 1920 to 1950, which did not have at least more than one observation.

Mr. Aldrich having been good enough to place these daily solar-constant results in my hands, I computed 10-day and monthly mean values from them for the 31 years 1920 to 1950. To have them in most convenient form for my use, I took their departures from the value 1.900 calories per square centimeter per minute and divided these departures by 1.940. Thus the results became expressed in percentage departures of the solar constant from 1.900 calories. In that form any well-evidenced periodic change resulting from a tabulation shows at once its amplitude in percentage of the solar constant. All values are positive as thus treated, which is convenient in tabulation. These data are given in table 4, appendix I.

PERIODS FOUND AND NOT FOUND

With these clarifying remarks, I now introduce the results. The following periodic changes in the solar constant were found well evidenced. Their approximate relation to 272 months and their amplitudes in percentage of the solar constant are given in table 1A.

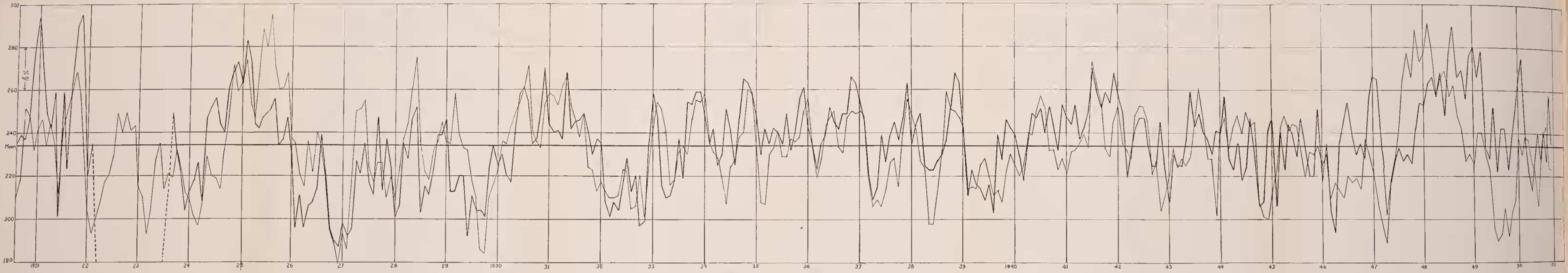

Fig. 4.—The march of solar variation, 1920 to 1950 (heavy lines), compared to a synthesis of the 23 regular periodicities given in table 2, shown here in light lines

The following periodic changes, given in table 1B, if real, are too small in percentage to be verified.

Tables 1A, 1B.—*Periodicities in solar-constant observations*

A. Periodicities confirmed *

Period Months	Amplitude Percent	Period Fraction of 272
2 1/7	0.05	1/127
3 1/20	0.05	1/90
4 1/3	0.06	1/63
5 1/18	0.05	1/54
6 1/30	0.12	1/45
7	0.08	1/39
8 1/14	0.06	1/34
9 1/10	0.08	1/30
9 7/10	0.10	1/28
10 6/10	0.06	1/26
11 1/5	0.17	1/24
11.43	0.11	1/24
12.0	0.20	....
13 1/10	0.11	1/21
15 1/6	0.09	1/18
22 3/4	0.07	1/12
24 3/4	0.12	1/11
30 1/3	0.13	1/9
34 1/2	0.15	1/8
39	0.20	1/7
45 1/2	0.13	1/6
54 1/2 †	0.13	1/5
68	0.25	1/4
91	0.12	1/3
272	...	1

B. Periodicities sought but not found

Period Months	Period Fraction of 272
4 1/2	1/60
5 1/2	1/50
6 1/2	1/42
7 5/6	1/35
8 1/2	1/32
10 1/9	1/27
10 9/10	1/25
13 6/10 †	1/20
14 4/10	1/19
17	1/16
18 1/5	1/15
19 1/2	1/14
21	1/13
24 8/10	1/11
136	1/2

* The periodicities of 11.43, 12.0 (the periodicity of 12 months is not used in preparing figure 4; if it were, that figure would present closer accord between the curves), and 24¾ months were added to the list after search among the departures of the synthetic values, found by summing 21 periodicities, from the observed solar-constant values. It is indeed curious to find *two* periodicities both within 1 percent of 1/24 of 272 months. Both of them are excellently evidenced and of good amplitude. The 12-month period is of terrestrial, not solar, causation. When one reflects that the pyrheliometer observes only about 70 percent of the solar constant, the remaining 30 percent being supplied by our estimates of atmospheric transmission, it is perhaps not surprising that the yearly (terrestrial) periodic error in the solar-constant values is as large as 0.2 percent in amplitude. The periodicity of 24¾ months was the only other one which could be discerned in a residual plot of differences, smoothed by 7-month running means.

† After this work was done, I computed a table of the periodicity 54 8/10 months in the precipitation of Peoria, Ill., 1856 to 1939. It showed *no* periodicity of 54 8/10 months, but *four* strong, well-shaped periodicities of 54 8/10 ÷ 4 = 13 7/10 months. Hence I think the sun's radiation has a periodic variation of one-twentieth of 22¾ years, though it did not impress me as real in the tabulation of the solar constant.

All periods of these two lists were separately sought for by tabulating over 1,000 solar-constant 10-day means for each suspected periodicity. The investigation does not cover entirely the years 1922 and

1923. I have elsewhere discussed the large solar change observed in those years.[5] I still think it was a real one. But it may be either a very unusual sporadic solar change, or it may be a periodic change related to a longer period than 272 months.

CONCERNING DOUBTS OF SOLAR VARIATION

For those who do not have intimate association with the Smithsonian observations of the solar constant of radiation, it seems difficult to accept the results as having the high degree of accuracy claimed for them. Observers, familiar with the clouds, dust, and water-vapor load which the lower atmosphere bears to make it milky, do not readily visualize a sky so clear that, if one holds his little finger at arm's length before the sun, the sky seems deep blue right down to the sun's edge. But even if the superior excellence of stations like Montezuma, Table Mountain, and St. Katherine be granted, it still seems incredible to many that the fraction, amounting to about 30 percent of the solar constant, cut off by the atmosphere, can be so correctly estimated that variations of the order of 1/10 percent of the solar constant can be evaluated.

Still more doubtful does it appear to many that, lacking any theoretical support, it can be proved from the observations that the solar variation consists of 23 simultaneously operating regular periodicities, all aliquot parts of $22\frac{3}{4}$ years. Yet it seems to me this cannot longer be doubted. I have tried to demonstrate by a couple of examples that it is necessary to use integral fractions of $22\frac{3}{4}$ years, rather than any other intervals, to represent the the sun's periodic variation. The two periods I have chosen to experiment upon are those which are 1/7 and 1/45 of $22\frac{3}{4}$ months. In figure 1 the longer period is plotted as 39 months.

I made a new tabulation in four parts for a period lying between 1/45 and 1/44 of $22\frac{3}{4}$ years. It was assumed to be $6\frac{1}{6}$ months, or 19 10-day intervals. In each of the four groups tabulated there are 14 columns. Taking the mean values, they are as plotted in figure 2,A. Evidently, if the four mean results were combined directly, they would so contradict each other that the general mean would show no periodicity at all. But the principal feature, marked A at its right-hand edge in each plot, is equally displaced from curve to curve toward the left by about 6 10-day intervals. The displacement is 19

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[5] Monthly Weather Rev., U. S. Weather Bureau, February 1923. Proc. Nat. Acad. Sci., vol. 9, No. 6, pp. 194-198, 1923. Smithsonian Misc. Coll. vol. 77, No. 5, 1925 (see fig. 11); vol. 80, No. 2, 1927.

10-day intervals, in all, from curve I to curve IV. Between these curves I and IV lies a stretch of time of about 800 10-day intervals. Hence the period should have been taken less than $6\frac{1}{6}$ months by $19/800 \times 6\frac{1}{6} = 0.146$. Subtracting from 6.163, this yields a corrected period of 6.017 months. Within the error of determination, this checks with 6.003, which is the period given in table 1C. Having displaced curves II, III, and IV by 6, 12, and 19 10-day intervals respectively, and having taken the general mean of the four and plotted it, the result appears in figure 2,B. It is to be compared with the curve of 6.033 months above it, representing the mean value as given in table 1C. It must be admitted that the agreement is striking.

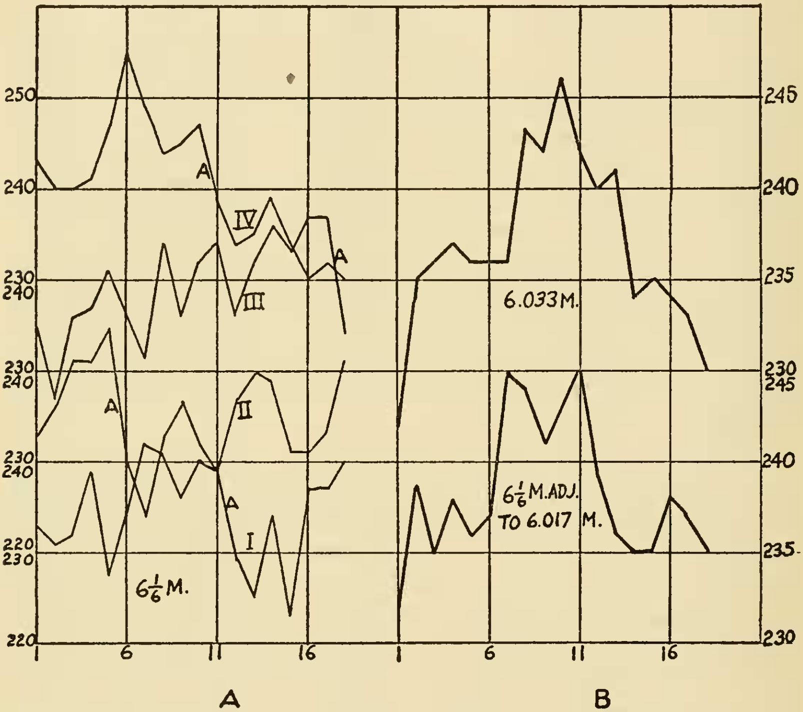

FIG. 2.—The periodicity 6.033 months, confirmed by the displacement of the feature A gradually from I to IV, when the period is assumed to be $6\frac{1}{6}$ months, as shown in figure A. In figure B this displacement is adjusted to a period of 6.017 months, which nearly agrees with the true period, 6.033 months.

Proceeding similarly, I computed two curves[6] for the seventh of

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[6] There being but four columns in these part computations for 39 and 37 months, the plots of the results are very ragged, owing to the disturbing influences of 22 other periodic factors superposed.

																			Σ	÷ 18	Adjusted places		Mean	Δ
1	254	237	211	206	201	232	288	273	180	252	154	237	237	201	242	191	211	227	3998	222	231	229	227	—10
2	239	288	263	211	232	211	299	263	211	216	216	258	247	237	191	211	216	232	4241	236	231	238	235	— 2
3	265	278	196	252	252	232	263	263	232	216	216	247	221	196	206	211	221	227	4205	234	234	239	236	— 1
4	263	299	227	252	211	278	258	242	191	227	247	221	216	227	191	216	206	232	4178	232	238	242	237	0
5	227	206	263	242	216	252	263	232	170	201	232	206	227	232	242	175	227	247	4115	229	233	245	236	— 1
6	227	242	268	237	196	268	252	237	201	206	201	211	242	211	227	206	232	242	4080	227	235	245	236	— 1
7	227	242	268	221	206	263	216	232	216	180	206	232	227	227	216	227	252	242	4105	228	236	244	236	— 1
8	278	242	294	237	221	263	221	216	201	185	242	232	263	252	216	237	242	263	4305	239	240	251	243	+ 6
9	206	242	309	221	237	268	258	252	206	185	216	247	247	237	227	237	242	268	4321	240	238	246	242	+ 5
10	278	267	294	227	252	273	247	242	211	201	253	242	247	237	206	237	273	278	4434	246	245	246	246	+ 9
11	258	247	283	211	252	283	237	247	196	170	221	227	278	227	175	227	258	263	4241	238	239	248	242	+ 5
12	201	263	309	221	297	263	247	237	216	201	227	201	232	252	196	211	232	216	4212	234	240	247	240	+ 3
13	294	185	273	216	247	273	258	258	211	191	232	221	232	242	206	232	278	247	4311	239	242	245	242	+ 5
14	263	206	247	175	263	242	263	237	221	206	216	196	221	258	211	232	273	268	4188	233	230	239	234	— 3
15	278	211	268	216	247	263	278	258	211	196	232	216	216	237	216	211	242	247	4238	235	232	239	235	— 2
16	299	258	165	211	268	283	206	196	211	191	211	237	191	232	201	232	268	258	4102	228	239	236	234	— 3
17	304	268	247	211	252	278	258	201	232	175	221	211	227	211	206	247	252	216	4284	238	234	228	233	— 4
18	278	252	247	221	278	283	221	206	232	242	232	201	227	196	206	232	247	227	4146	230	227	234	230	— 7
19					221					160					211									
																					Mean	237		

																				÷ 18
1	237	232	206	237	206	263	258	263	237	237	232	252	211	227	206	247	227	227	4205	234
2	258	263	191	211	211	263	232	268	242	242	237	252	216	242	237	263	201	258	4289	238
3	237	263	221	180	227	237	221	263	227	242	237	242	180	247	237	268	211	258	4198	233
4	237	221	211	201	191	263	221	268	247	247	237	268	227	247	227	268	221	221	4223	235
5	237	237	232	211	196	242	227	263	232	268	232	273	237	247	206	268	211	227	4246	236
6	288	221	227	185	206	263	242	258	247	252	247	258	237	258	211	258	211	258	4327	240
7	258	232	154	201	232	273	221	268	237	247	258	278	237	252	227	273	196	242	4286	238
8	258	237	206	258	206	268	242	258	237	263	252	263	242	278	232	258	221	237	4416	245
9	247	221	221	237	216	252	258	247	247	273	247	247	221	232	227	242	221	242	4298	239
10	247	247	221	211	232	258	252	242	247	237	252	247	227	268	232	237	227	237	4321	240
11	232	242	263	258	247	258	258	268	227	263	242	273	232	206	221	242	201	227	4360	242
12	232	242	206	247	242	237	232	232	232	227	242	242	242	221	227	216	201	227	4147	230
13	252	242	216	268	221	247	232	237	247	242	232	247	232	237	232	185	180	232	4181	232
14	247	221	196	258	221	263	211	237	263	263	252	237	242	273	232	232	227	232	4307	239
15	247	227	227	242	221	216	237	216	237	196	242	252	252	268	237	221	252	211	4201	234
16	258	232	216	242	216	227	227	221	232	201	232	211	247	237	232	216	232	211	4090	227
17	232	165	191	237	252	247	232	242	237	237	252	221	237	242	242	232	232	227	4157	231
18	252	175	232	206	247	221	247	263	227	232	262	227	242	232	247	221	221	211	4165	231
19		221					263					201					237			

Adjusting period

$$\frac{4}{700} \times 6 = 0.034$$

$$6.067 - 0.034$$

is 6.033

or 6 1/30

																					Σ	÷ 20
1	268	252	221	247	227	237	242	237	242	237	237	242	252	237	216	247	263	283	242	263	4892	245
2	242	252	247	268	242	242	232	247	237	232	242	252	227	232	211	258	283	278	232	242	4898	245
3	237	227	216	247	257	257	237	206	227	237	232	221	258	304	247	237	273	283	191	288	4882	244
4	268	216	263	247	257	232	252	232	237	268	227	216	247	273	242	263	273	278	242	288	5021	251
5	247	242	263	263	237	211	263	227	221	232	227	216	258	221	237	278	299	278	237	268	4925	246
6	252	258	216	258	247	227	263	263	227	201	258	221	237	278	232	247	288	247	242	268	4930	246
7	242	258	268	283	252	206	252	252	237	211	242	227	258	258	211	263	283	273	247	227	4950	248
8	258	232	258	288	257	206	221	242	227	206	242	258	221	258	216	273	283	309	242	237	4934	247
9	252	268	268	237	232	211	257	227	237	242	247	211	221	216	221	268	278	294	263	247	4897	245
10	242	242	283	247	232	216	247	257	263	247	232	201	216	237	252	258	237	232	221	227	4789	239
11	242	216	283	247	237	242	242	263	216	232	221	201	252	242	221	278	252	242	227	227	4783	239
12	237	247	252	252	237	232	257	252	206	232	232	191	252	185	237	247	278	252	237	211	4726	236
13	242	273	242	247	247	247	206	216	206	232	216	185	232	206	221	247	278	206	206	221	4561	228
14	263	258	278	221	196	247	247	242	221	206	211	206	221	216	227	293	258	221	232	211	4675	234
15	252	232	263	221	232	221	242	227	191	232	232	252	216	191	237	252	258	206	221	206	4584	229
16	242	268	216	216	232	211	232	216	232	253	221	242	232	227	263	258	253	258	263	232	4767	238
17	247	247	273	227	227	227	247	227	206	247	206	211	237	232	273	258	278	242	268	206	4786	239
18	227	242	258	237	216	237	232	227	185	237	258	252	247	232	242	252	268	273	247	247	4816	242
19				232					247					232				7	237			

Mean values when plotted show progressive displacement.

Total displacement, 4 places on 700 places.

$22\frac{3}{4}$ years, assumed as 39 months. In this new tabulation I used monthly mean values, instead of 10-day means, as had been done in computing for the curve shown in figure 1. I also computed two curves for a period of 37 months. They show opposition rather than similarity. It now appeared that in both the 39-month and the 37-month computations, the principal features were displaced toward the right in the second half of the 31-year interval. The corrected interval from the 39-month tabulation is $39\frac{1}{2}$ months. Plots of the 37-month tabulation shown in figure 3,A indicated a displacement toward the right of 8 months in an interval of 180 months of time. This gives a positive correction of $\frac{8}{180}\times 37 = 1.6$ months. Thus combined, the contrary curves of figure 3,A yield the lower curve of figure 3,B. Thus the 37-month tabulation yields an adjusted period of 39.6 months, closely agreeing with that yielded by the adjusted 39-month tabulation which was 39.5 months. This later period agrees within slightly more than 1 percent of being $\frac{273}{7}$, or 39.0 months. (See figure 3,B.)

If critics feel that still more evidence is needed to prove that only integral fractions of $22\frac{3}{4}$ years are to be found in the solar variation, I will remind them that many of the periodicities plotted in figure 1 show integral fractions of the periods in question superposed upon them. Conspicuous examples in figure 1 are periodicities of $15\frac{1}{6}$, $34\frac{1}{2}$, 39, $45\frac{1}{2}$, and $54\frac{1}{2}$ months.

ACCURACY OF DATA

As shown in Annals of the Astrophysical Observatory of the Smithsonian Institution (vol. 6, p. 163), the comparison of daily solar-constant values, independently measured at stations thousands of miles apart, in opposite hemispheres of the earth, extending over many years, yields a probable error for a well-observed solar-constant value, resulting from work of two stations on a single day, of $\frac{0.164}{\sqrt{2}}$ percent or $\frac{1}{8}$ percent. Using the familiar relation (the probable error of a mean is that of the individual divided by the square root of the number of values), this indicates that a 10-day mean of good quality should be assigned a probable error of 1/25 percent. Then if nine such 10-day means are tabulated in searching for a solar periodicity, the probable error of their mean becomes only 1/75 percent. These considerations indicate not only that real solar variations of 1/10 percent of the solar constant might be detected, but that the features of the march of a periodic variation of this small amplitude would appear well delineated from a tabulation.

To be sure, these optimum conditions do not always prevail. Not infrequently no more than three or five days of a decade yielded solar-constant observations. Often no more than one station reported. During parts of the year less favorable conditions prevailed at one or other of the stations. Such is the case at Table Mountain from March through June, and at Montezuma from November through January. (See figs. 7, 8, pp. 70, 71, Annals, vol. 5.)

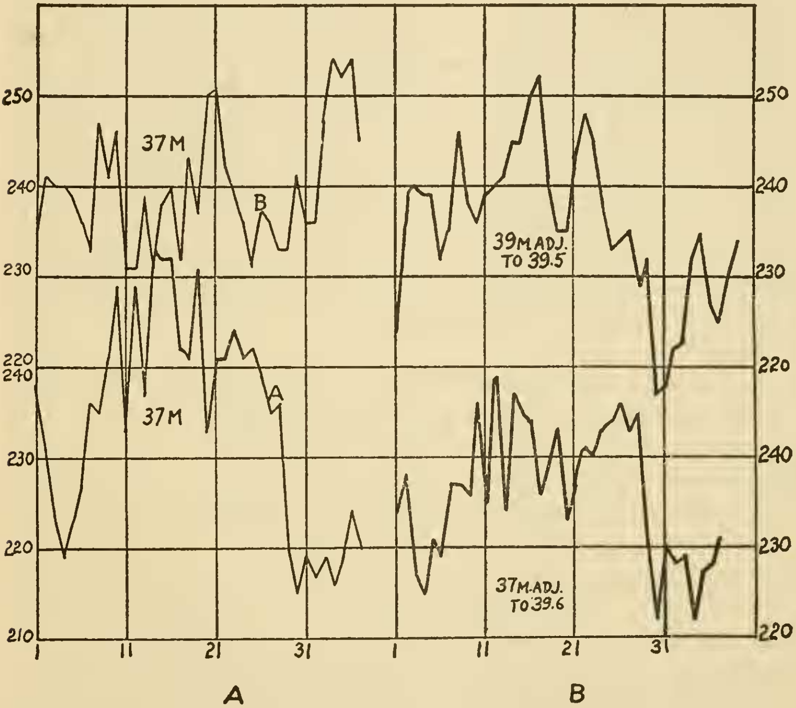

FIG. 3.—The periodicity of approximately 1/7 × 272 months, tested just as the periodicity of approximately 1/45 × 272 months was tested in figure 2.

On these accounts it need not surprise us that, as shown below, while the sum of periodic variations represents the variation of monthly mean solar-constant results to within an average deviation of 1/10 percent, much larger departures sometimes occur. However, divergences depend not only on accidental errors of the observations, but, in part also on imperfect determination of the form, amplitude, and period of the periodicities, for reasons explained above.

SUPPORTING EVIDENCES OF VERIDITY OF PERIODICITIES

There are several indications, not flowing from a consideration of probable errors, that strongly support the veridity of periodicities here disclosed:

1. In tabulating periodicities, the data have been treated independently in several parts. That is to say, there being nearly 1,100 consecutive 10-day means covering an interval of 30 years, it is possible to tabulate in three or more groups, each with numerous columns, all periodicities of less than 20 months in length. For periodicities of between 20 and 40 months I use two tables, covering consecutive intervals of time. (See fig. 1.) Unless these independent part-tabulations agree within their measure of accuracy to indicate continuance of the same form of periodic variations, and with maxima in the same phase throughout the whole time, then such a supposed period is thrown out as nonexisting. For periods exceeding 40 months, the data were not numerous enough to be thus separated into several groups.

2. There is an integral relationship between the periods disclosed. All the periods, which the first criterion certifies as veridical, are, to within a deviation of 1 percent, integral submultiples of 272 months. For example, those approximately 91, 68, 54, 45, 39, 34, 30, and a dozen others of shorter period, are all integral fractions, to within 1 percent, of 272 months. We know that a period of about 272 months is related to the average sunspot period of 11⅓ years, and it was found by G. E. Hale in the behavior of sunspots and magnetism. It is also approximately the period discovered by meteorologists in many climatic phenomena, as well as by Douglass in the growth of trees.

I cannot but think that the fact of the integral relationship, each to each, of the solar-radiation periodicities here disclosed, and the relationship of all of them to a master period of 272 months, well known in other solar and terrestrial phenomena, strengthens the case for validity of these periodicities. If that be granted, surely the existence of these integral solar-radiation relationships, so reminiscent of the overtones of the vibrations of musical instruments, is a phenomenon well worth investigating by astronomers and by students of hydrodynamics.

I have just stated three arguments for the reality of numerous regularly periodic variations of the output of radiation from the sun as follows: A. Measurements whose small probable error is consistent with the amplitudes of the apparent periodicities display them. B. Tabulations of a chosen periodicity, with the data separated into independent groups, covering successive time intervals, show separately the periodicity in similar amplitudes, forms, and phases. C. The periods are integrally related, each to each, and all are approximately exact integral submultiples of 272 months, itself a well-known period in other solar and terrestrial phenomena. A fourth supporting evidence is to be referred to later.

The argument B is undoubtedly the most telling. In order to display its full weight, I give, in figure 1, a résumé of all the periodicities which I consider real. It is my firm expectation that scientists who examine without bias the arguments A, B, and C and carefully scan figure 1 and table 1C, will yield to the conviction that the sun's contribution of radiation that warms the earth varies in a complex way. In short, they will admit that, like the overtones of a musical note, the radiation of the sun varies simultaneously in a period of approximately 272 months, and in periods, exceeding 20 in number, which are integral submultiples of approximately 272 months. If scientists go thus far, I cannot but think they will go farther and investigate theoretically the hydrodynamics of the phenomenon.

PERIODICITIES OF 22¾ AND 11⅜ YEARS

I have not tabulated the data so as to display the periodicity of 272 months, because the values are insufficient. There would be too few repetitions to fairly fix the form of this curve. As for the periodicity of $\frac{272}{2}=136$ months, though it is the well-known 11⅓-year sunspot period, it is inconspicuous in the variation of the solar constant. I have twice sought for it. First, I tabulated the original data in columns of 136 months and smoothed their mean values. Second, I smoothed by 7-month running means the residual departures, which separate the original data from the synthetic reproduction of them in figure 4 by 23 periodic terms. Neither treatment gave conclusively a periodicity of 136 months. Its well-evidenced weather influence, I think, is attributable to fluctuation of the intensity of the bombardment of the atmosphere by electric ions, acting as centers of condensation of water vapor and dust, as sunspot numbers wax and wane.

GRAPHS OF RESULTS

Figure 1 is introduced to emphasize the force of the argument B by a graphical appeal to the eye. The figure shows the mean result of every partial tabulation of the values used to compute table 1A, and also the general mean of these partial tabulations for almost all periodicities included in table 1A. Curves for periodicities of 2 1/7 and 3 1/20 months are given on a scale of abscissae 2½ times as great as the other curves. Horizontal lines in figure 1 are separated by 1/10 percent of the solar constant. The curves for periodicity 2 1/7 months are given on a scale of ordinates twice as great as that used for all others. Up to a periodic length of 22¾ months, all the curves are plotted at 10-day intervals. Periodicities of 22¾ months and longer are plotted in monthly intervals. Of periodicities less than 22¾ months in length, one, that of 9 1/10-months period, is shown smoothed throughout by 5-decade running means. It has a small amplitude and would perhaps have seemed doubtful to many had not running means of 5-decade values been shown, instead of the separate 10-day mean values. This smoothing brings out plainly the similarity of the partial tabulations.

The amplitudes of the 23 periodicities plotted in figure 1 may seem to some critics too small to be of any significance. Not so. For it is shown in figure 4 that the synthesis of these 23 periodic fluctuations produces a curve closely matching, and of the same amplitude of variation as, the curve of original observation. A 12-month period of terrestrial origin with amplitude of 0.2 percent is not introduced into figure 4. Its inclusion would improve the agreement there. No additional regular periodicities were discernible. The analysis appears to be exhaustive.

As the periods grow longer, they are apt to display integral submultiples riding upon the period under examination. This is strongly marked with the period of 15⅙ months. It shows seven subperiods of 2 1/7 months very plainly. Similarly the 30½-month curve shows also the 6 1/30-month influence. The 34½-month curve shows influence of the 11¼-month period. Other examples are obvious. Note the curves for periodicities of 54½, 68, and 91 months shown in figure 1. Owing to superposed periods of less length, these long periodicities had to be smoothed by 5- or 7-month running means.

In addition to the direct mean results for each period, I give in a few cases also the smoothed mean, resulting from taking 5-value or 7-value running means for the entire length of the periodicity under consideration. These smooth curves give a more convincing and truer idea of the periodicities, thought to be real, than do the rougher direct means, affected by accidental errors of observation and influences of extraneous periods. Readers should bear in mind that the knicks in the broken lines, which look so large, really average less than 1/10 percent of the solar constant. This bears witness to the high accuracy of the Smithsonian solar-constant observing. Its probable error has been discussed above.

INTEGRAL RELATIONSHIPS

I had long been of the opinion that the regular periodicities of solar variation are all integrally related to approximately 272 months. This impression is supported by the fact, so obvious in figure 1, that the longer periods shown, themselves being integrally related to 272 months, have in several instances shorter periodicities riding on their backs, which are integral submultiples of them. Further proof of the integral relationships is shown in figures 2 and 3, already described.

Assuming that this integral relationship to 272 months is a condition necessary to the real existence of a regular period in solar variation, the number of such periods that are of considerable amplitudes seems not to exceed 23. At least a rather extensive search has not yielded others strong enough to be certainly real. If these be all, and their forms and amplitudes are as shown in figure 1, then a synthesis of them ought to represent the march of solar variation from 1920 to 1950, except for the interval of 1922 and 1923, when exceptionally large solar variations were observed and which is excluded from this analysis. I have made such a synthesis, and compare it with the march of the solar variation in figure 4.

SYNTHESIS OF PERIODICITIES

To determine the quantities plotted in figure 4, I have computed the departures, plus and minus, from the mean ordinate for each smoothed periodicity, as expressed monthly, which together fix the form of its curve. This gives, in each case, a short series of small monthly departures suitable to the form of each periodicity. All the tabulations begin with August 1920 as zero time. In table 2 they are all tabulated in the smoothed form actually used in preparing the synthetic curve shown in figure 4. In computing the mean periodic forms, and afterward in using them for synthesizing the solar-constant values, I allow for fractions of a decade, or of a month, by adding or withdrawing a value from certain columns, or at appropriate intervals in synthesizing, so as to preserve the correct period.

I tabulate these series, end to end, over the whole interval of more than 30 years. Thus I make a great table of 23 columns and 367 lines. Adding algebraically the plus and minus values of the lines across the table, I find the total synthesized monthly departures, in ten-thousandths of the solar constant, from the mean solar constant 1.94 calories. The results, covering 367 months, are compared in figure 4 with the monthly observational values recorded in table 4.

CLOSE AGREEMENT BETWEEN SYNTHESIS AND OBSERVATION

Table 3, below, shows the high degree of accuracy with which the synthesis of the original 21 periodicities (before those of 11.43 and $24\frac{3}{4}$ months were found) corresponded to the observations.

These results came from the comparison of observation with the synthesis of 21 periodicities. The average departures are reduced below these figures when periodicities of 11.43, 12.0,[7] and $24\frac{3}{4}$ months are introduced. The value for the best 233 months then becomes 1.00-tenths percent. The larger average departures prior to July 1926 are attributable to the then imperfect development of the "short method" of solar-constant work. The larger departures after 1945 are thought by Mr. Aldrich to be caused by temporary errors in the scales of pyrheliometers used in the field. He hopes to correct this discrepancy.

Some minds may still prefer to think that the solar-constant observations do not prove the variability of solar radiation. They may point out that the average deviation of the observations from their mean is 0.15 percent, and the average deviation of the synthetic curve from that of observation is still 0.10 percent. They may urge that this amount of improvement is not sufficient to warrant belief in the thesis that the sun's radiation varies in the discovered 23 regular periods, all integral submultiples of 272 months.

Such critics may be reminded that the "weight" of any measurement, that is, its claim to respectful recognition, is proportional to the number of observations that enter into the result; but the probable error (proportional to the average deviation from the mean) is proportional to the square root of the number of observations. It follows that the "weight," or credibility of a solution, is proportional to the square of the average deviation of its components. Hence the weight of the solution here advocated is $\left(\frac{15}{10}\right)^2 = 2.25$ times the weight of the conclusion of an invariable sun.

But it must also be considered that a certain irreducible minimum of accidental error, comparable in a graph to the teeth of a saw, adheres to the solar-constant observations. Whatever excursions from the mean value may be produced by real solar variations, these acci-

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[7] The 12-month period is not used in preparing figure 4; its use would improve the agreement of the curves.

TABLE 2.—*Twenty-three solar periodicities in ten-thousandths of the solar constant, based on August 1920. Also the 12-month terrestrial period, same unit*

2 1/7 M: +2 −2. 3 1/20 M: 0 −2 +2. 4 1/3 M: −1 −2 +3 ±0.

5 1/18 M: −1 ±0 −2 +2 +2. 6 1/30 M: −4 −1 +3 +6 ±0 −5.

7 M: −1 +1 +5 +2 −1 −1 −2. 8 1/14 M: −2 −2 −1 −1 +1 +1 +3 +2.

9 1/10 M: −2 −4 −3 −1 ±0 +2 +3 +1. ±0.

9 7/10 M: −4 −3 −1 +1 +5 +5 +2 −1 −4 −3.

10 6/10 M: −1 −1 −1 −1 −3 +1 +1 +2 +3 +1 −1.

11 1/5 M: −4 −2 ±0 +3 +1 +9 +3 −1 +4 −2 −8.

11.43 M: +7 +4 +6 +1 −3 −4 −3 −3 −4 −3 −1.

13 1/10 M: +1 +4 +3 −2 −6 −4 +2 +2 +1 ±0 −2 +1 +3.

15 1/6 M: −3 −6 −6 −1 ±0 +2 +1 +2 +3 +2 ±0 ±0 +2 +1 +1.

22 3/4 M: −1 +1 ±0 +1 +1 +1 +1 +1 ±0 ±0 +1 +2 +3 +3 +2 +2 +1 −1 −2 −3 −3 −2 −1.

24 3/4 M: −2 −2 −1 +1 +2 +3 +3 +4 +4 +4 +3 +3 +2 +1 ±0 −2 −5 −7 −2 ±0 ±0 ±0 ±0 −1 −1.

30 1/3 M: +6 +5 +4 +3 +3 +4 +3 +1 +1 ±0 ±0 ±0 −1 −3 −5 −6 −6 −5 −5 −6 −6 −4 −3 −2 −1 −1 ±0 +3 +3 +4.

34 1/2 M: −5 −6 −4 −3 −3 −2 −3 −5 −7 −6 −3 −1 −1 +2 +5 +6 +8 +7 +6 +4 +1 −1 ±0 +1 +2 +3 +3 +4 +5 +5 +2 +1 −1 −3.

39 M: −4 +1 +2 +2 +2 +2 +1 +1 +1 +2 +2 +4 +6 +8 +10 +10 +8 +7 +5 +3 +4 +5 +5 +4 +3 +3 +1 −1 −4 −6 −8 −10 −10 −10 −9 −9 −9 −8 −6.

45 1/2 M: −3 −4 −3 −3 −2 −1 ±0 +1 +1 +3 +4 +6 +6 +3 +2 +1 ±0 −2 −3 −1 −1 +1 +1 +2 +3 +2 +2 ±0 −1 −3 −4 −5 −4 −3 −2 ±0 +1 +1 ±0 −2 −3 −4 −2 −2 −1.

54 1/2 M: +4 +4 +5 +6 +6 +7 +7 +7 +7 +6 +6 +6 +5 +3 ±0 −1 −1 −1 −2 −4 −4 −3 −3 −2 −2 −2 −2 −3 −2 −3 −2 −4 −5 −4 −3 −4 −2 −3 −3 −4 −3 −2 −1 −1 −1 −2 −1 ±0 ±0 −2 −2 −1 +1 +2.

68 M: −7 −5 −4 −4 −4 −6 −6 −8 −12 −13 −12 −9 −5 −4 −2 −3 −2 −2 −8 −11 −11 −10 −6 −6 −4 −3 −4 −4 −3 −5 −5 −6 −5 −4 −4 −4 −4 −6 −7 −8 −7 −8 −6 −4 −2 ±0 +2 +4 +5 +6 +7 +8 +9 +10 +10 +11 +11 +12 +12 +11 +11 +10 +8 +5 +2 −2 −3 −7.

91 M: ±0 +1 +2 +2 +2 +2 +2 +3 +4 +2 +1 −1 −2 −3 −3 −3 −4 −4 −4 −3 −3 −3 −3 −4 −4 −4 −4 −3 −2 −1 ±0 ±0 ±0 ±0 ±0 −1 −2 −3 −3 −4 −4 −4 −4 −4 −4 −4 −4 −4 −3 −2 −1 ±0 +1 +2 +2 +3 +4 +5 +6 +6 +7 +7 +7 +7 +7 +6 +5 +4 +3 +2 +2 +1 +1 +1 ±0 ±0 −1 −2 −2 −3 −4 −4 −4 −4 −3 −2 −1 −1 ±0 ±0 ±0.

The 12-month period of terrestrial causation

Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
+0.1	+0.6	−2.1	−6.7	−0.9	+1.7	+1.4	+2.1	+4.3	+6.2	+13.2	+13.5

dental errors of observation will still load the curve with their sawtoothlike vibrations about its true course. No system of periodicities, which may truly represent the true courses of the solar variation, can possibly follow these small accidental errors of observation. It is therefore unreasonable to demand that such a system of periodicities, even though the true one, can be expected to reduce the average deviation of its curve from the curve of observation below the one-tenth of a percent found. For though, as stated, the probable error of *first-rate* 10-day means, as found by comparing the simultaneous observations of two solar-constant observations, is 1/25 percent, very many 10-day means are not first rate, as explained above. Moreover the "average deviation" is 5/4 of the "probable error," as is well known, raising the figure to 1/19 percent for the average deviation of first-rate 10-day means.

Table 3.—*Average departures of synthetic from observational curve*

Aug. 1920—Mar. 1922,	20 months,	2.01	tenths	percent.
Aug. 1923—July 1926,	36 months,	1.82	"	"
Aug. 1926—Dec. 1945,	233 months,	1.10	"	"
Jan. 1945—Dec. 1950,	60 months,	2.38	"	"
Aug. 1920—Dec. 1950,	349 months,	1.45	"	"

The real crux of the question, as between the hypothesis of constant solar radiation, and solar radiation varying in 23 regular periods, painstakingly determined and tested by several criteria of reality, lies in considering the large excursions of the curve of observation from its mean. Examples of such methodically marching excursions are found from 1924 to 1927, from 1929 to 1933, from 1937 to 1942, and from 1947 to 1949. The hypothesis of a constant solar radiation offers no explanation for them. On the other hand, the synthetic curve follows these large, methodically marching excursions with some fidelity.

Yet notwithstanding this striking harmony in the principal features between the curve of observation and the synthetic curve of regular periodicities, there are limited intervals of substantial disagreement. Among these the major one occurs in 1922 and 1923, regarding which I have already written. The disagreement in 1920 and 1921 may be attributed to the incomplete development of the short method of solar-constant determination in those earliest years. The same perhaps applies to the disagreement in the years 1924 and 1925, for even then the short method was not fully developed, as now used. As for the period 1946 to 1950, Mr. Aldrich inclines to think the scales of pyrheliometry may have varied a little in those years. There is also a possibility that, in carrying the computations so far forward as 1950 from their base in 1920, slight errors in the length of the periods have accumulated so as to mar the results of synthesis.

Brief intervals of unusually large divergence between the synthetic and the observed curves occur in 1927, 1929, 1934-1935, 1938, 1940-1941, and 1944. Nearly all these cases occur at the times of the year when sky conditions for observing are inferior at one or both stations, as indicated by figures 7 and 8, pages 70 and 71, Annals, volume 5, already cited. It is not probable, however, that regular periods of variation include *all* the variations of solar radiation. We know, indeed, that outbursts of sunspots and flares cause changes in the sun's output of radiation. Some of the discrepancies referred to are doubtless due to such causes.

I hope the reader will agree that the synthesis of 23 independently and separately computed periodic terms has represented, to within the error of observation, the march of the solar constant as given by the monthly means of the original observations from 1920 to 1950, excluding the extraordinary values of 1922 and 1923. This close agreement in form and amplitude between the observed and the synthetic curve seems to me a fourth kind of evidence supporting the existence of a complex of over 20 regular periods all approximately integral submultiples of 272 months in the observed variation of the sun's output of radiation.

It will occur to the reader that curves of solar observation should tend to repeat their features after 272 months, or approximately 23 years. There is a slight indication that the curve of 1921 in figure 4 is similar to that of 1944, but the work of 1921, as mentioned elsewhere, is too inaccurate to prove it. In the years 1922 and 1923 occurred a unique large depression of the curve of observation. A real test must begin with the year 1924. Unfortunately, as stated elsewhere, there appears to have been a change of scale of about $\frac{1}{3}$ percent in 1948. To correct for it, I subtract 32 units from all the monthly means, July 1948 to February 1950.

In figure 4A, I superpose the corrected curve 1947 to 1950 (light line) upon the observed curve of observation 1924 to 1927 (heavy line). The similarity is striking. During 48 months there are five large divergencies: 0.55, 0.50, and three of 0.45 percent. The extreme range of the great feature shown in figure 4A is 0.9 percent, and the average deviation between the curves is but 0.19 percent—less than the expected combined probable errors of observing. One regrets that the interval, 276 months, exceeds the expected interval, 272 months. But as solar conditions modify the lengths of the sunspot cycles, they may also slightly modify that of the 272-month cycle from time to time.

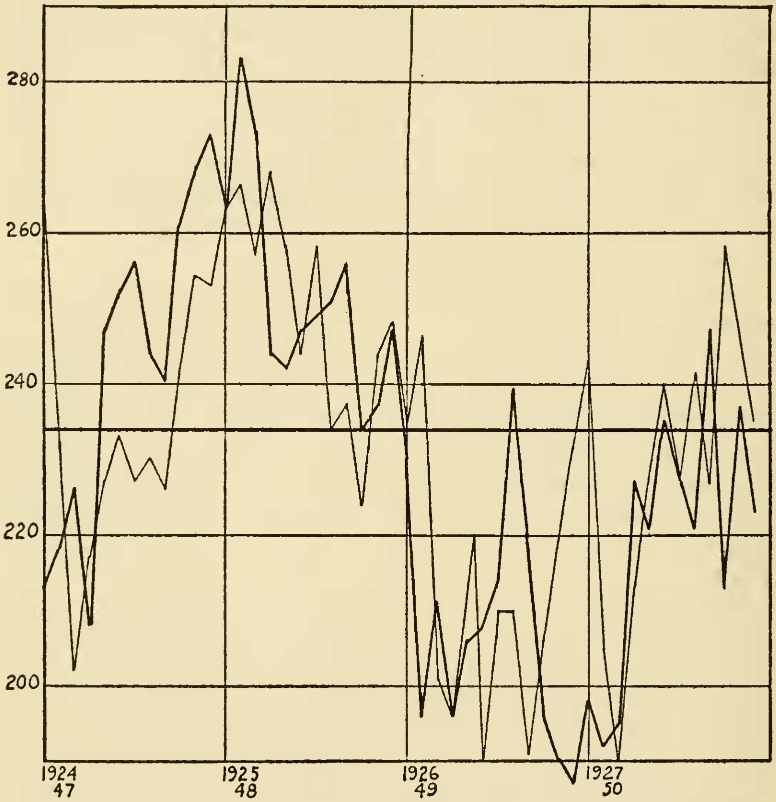

FIG. 4A.—Comparison of solar constants 1924-1927 (heavy lines) and 1947-1950 (light lines).

SCALE OF SOLAR CONSTANT NEARLY UNCHANGED IN 30 YEARS

It is very pleasing that the comparison of synthesized and original curves shows the features generally with equal amplitudes in the two curves. The comparison gives no indication that the scale of observation has changed in 30 years, except perhaps for a rise of 3/10 percent from June 1948 to January 1950. This is remarkable in view of many changes of instruments and of procedures that have taken place meanwhile.

APPENDIX 1

SOLAR-CONSTANT MONTHLY AND 10-DAY MEANS, 1920–1950

Doubtless there are those who are engaged in research on cycles in various lines who may wish to know the Smithsonian results on solar variability as nearly as possible up to date. Mr. Aldrich kindly permits me to publish the following table (table 4) giving the percentage excesses of solar-constant values above 1.900 calories from 1920 to 1950. These percentage excesses are in the form of means of 10 days (i.e., decades of months) and means of months. Taking the first trio of values, given here for illustration, the table may be explained as follows. We have:

2, 8, I, 0, 1, 154
2, 8, II, 0, 2, 139, 153[8]
2, 8, III, 0, 3, 165

The above figure 2, with the figure 0, makes 20, meaning the year 1920. The figure 8 means August, the eighth month of 1920. The Roman numerals I, II, III stand for the first, second, and third decades of August. That is: August 1-9, 10-19, 20-31. The values 154, 139, 165 represent decade-means of the daily excesses of the solar constant by which these observations exceeded in ten-thousandth parts of the mean solar constant (taken as 1.94 calories) the value 1.9000 calories. Thus the value 154 signifies that the mean solar constant for the first decade of August 1920 was 1.54 percent of 1.94 or 0.0299 calorie above 1.90 calories. Finally, the value 153 is the mean of the three decade values and signifies that the average solar constant for August 1920 was 1.90+1.53 percent of 1.94 calories, or 1.930 calories.[8] As stated above, the percentages of excess over 1.90 calories was chosen to suit my investigation because, first, all values are positive, and second, results come out in percentages of the solar constant.

APPENDIX 2

PROBABLE SOLAR-CONSTANT VALUES BEFORE 1920

Smithsonian solar-constant observations were made in the summers on Mount Wilson, Calif., in most years from 1905 to 1920. But partly because of experimental crudity, and partly from the variability of sky transparency, and mainly because those measurements were all made by the fundamental "long method," which requires constant sky transparency for hours, the results were wide-ranging, from about

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[8] This result is far out of line, and indicates experimental error. In drawing figure 4 I have assumed, instead, 235, given in parenthesis in table 4.

TABLE 4.—*Ten-day and monthly means*

2, 8	I, 0	1	154	
	II	2	139(235)	
	III	3	165	153
2, 9	I, 0	4	263	
	II	5	227	
	III	6	227	239
2, 10	I, 0	7	227	
	II	8	278	
	III	9	206	237
2, 11	I, 0	10	278	
	II	11	258	
	III	12	201	246
2, 12	I, 0	13	294	
	II	14	263	
	III	15	278	278
2, 1	I, 1	16	299	
	II	17	304	
	III	18	278	294
2, 2	I, 1	19	237	
	II	20	288	
	III	21	278	268
2, 3	I, 1	22	299	
	II	23	206	
	III	24	242	249
2, 4	I, 1	25	242	
	II	26	242	
	III	27	242	242
2, 5	I, 1	28	267	
	II	29	247	
	III	30	263	259
2, 6	I, 1	31	185	
	II	32	206	
	III	33	211	201
2, 7	I, 1	34	258	
	II	35	268	
	III	36	252	259
2, 8	I, 1	37	211	
	II	38	263	
	III	39	196	223
2, 9	I, 1	40	227	
	II	41	263	
	III	42	268	253
2, 10	I, 1	43	268	
	II	44	294	
	III	45	309	290
2, 11	I, 1	46	294	
	II	47	283	
	III	48	309	295
2, 12	I, 1	49	273	
	II	50	247	
	III	51	268	263
2, 1	I, 2	52	165	
	II	53	247	
	III	54	247	220
2, 2	I, 2	55	206	
	II	56	252	
	III	57	247	235
2, 3	I, 2	58	221	
	II	59	201	
	III	60	154	192
2, 4	I, 2	61	165	
	II	62	165	
	III	63	139	156
2, 5	I, 2	64	139	
	II	65	160	
	III	66	165	156
2, 6	I, 2	67	129	
	II	68	72	
	III	69	72	91
2, 7	I, 2	70	21	
	II	71	88	
	III	72	72	60
2, 8	I, 2	73	98	
	II	74	124	
	III	75	103	108
2, 9	I, 2	76	160	
	II	77	52	
	III	78	88	100
2, 10	I, 2	79	144	
	II	80	129	
	III	81	93	122
2, 11	I, 2	82	134	
	II	83	154	
	III	84	98	129
2, 12	I, 2	85	124	
	II	86	113	
	III	87	118	118
2, 1	I, 3	88	232	
	II	89	185	
	III	90	154	190
2, 2	I, 3	91	160	
	II	92	142	
	III	93	77	126
2, 3	I, 3	94	160	
	II	95	175	
	III	96	160	165
2, 4	I, 3	97	175	
	II	98	134	
	III	99	165	158
2, 5	I, 3	100	175	
	II	101	180	
	III	102	191	182
2, 6	I, 3	103	118	
	II	104	170	
	III	105	165	151
2, 7	I, 3	106	180	
	II	107	144	
	III	108	227	184
2, 8	I, 3	109	216	
	II	110	206	
	III	111	211	211
2, 9	I, 3	112	252	
	II	113	252	
	III	114	242	249
2, 10	I, 3	115	237	
	II	116	221	
	III	117	237	232
2, 11	I, 3	118	221	
	II	119	227	
	III	120	211	220
2, 12	I, 3	121	221	
	II	122	216	
	III	123	175	204
2, 1	I, 4	124	216	
	II	125	211	
	III	126	211	213
2, 2	I, 4	127	221	
	II	128	201	
	III	129	232	218
2, 3	I, 4	130	252	
	II	131	211	
	III	132	216	226
2, 4	I, 4	133	196	
	II	134	206	
	III	135	221	208
2, 5	I, 4	136	237	
	II	137	252	
	III	138	252	247
2, 6	I, 4	139	247	
	II	140	247	
	III	141	263	252
2, 7	I, 4	142	247	
	II	143	268	
	III	144	252	256
2, 8	I, 4	145	278	
	II	146	221	
	III	147	232	244
2, 9	I, 4	148	211	
	II	149	232	
	III	150	278	240
2, 10	I, 4	151	252	
	II	152	268	
	III	153	263	261
2, 11	I, 4	154	263	
	II	155	268	
	III	156	273	268
2, 12	I, 4	157	283	
	II	158	263	
	III	159	273	273
2, 1	I, 5	160	242	
	II	161	263	
	III	162	283	263
2, 2	I, 5	163	278	
	II	164	283	
	III	165	288	283
2, 3	I, 5	166	299	
	II	167	263	
	III	168	258	273
2, 4	I, 5	169	263	
	II	170	252	
2, 4	III, 5	171	216	244
2, 5	I, 5	172	221	
	II	173	258	
	III	174	247	242
2, 6	I, 5	175	237	
	II	176	247	
	III	177	258	247
2, 7	I, 5	178	263	
	II	179	278	
	III	180	206	249
2, 8	I, 5	181	258	
	II	182	221	
	III	183	273	251
2, 9	I, 5	184	263	
	II	185	263	
	III	186	242	256
2, 10	I, 5	187	232	
	II	188	237	
	III	189	232	234
2, 11	I, 5	190	216	
	II	191	252	
	III	192	242	237
2, 12	I, 5	193	247	
	II	194	237	
	III	195	258	247
2, 1	I, 6	196	237	
	II	197	258	
	III	198	196	230
2, 2	I, 6	199	201	
	II	200	206	
	III	201	180	196
2, 3	I, 6	202	211	
	II	203	232	
	III	204	191	211
2, 4	I, 6	205	170	
	II	206	201	
	III	207	216	196
2, 5	I, 6	208	201	
	II	209	206	
	III	210	211	206
2, 6	I, 6	211	196	
	II	212	216	
	III	213	211	208
2, 7	I, 6	214	221	
	II	215	211	
	III	216	211	214
2, 8	I, 6	217	232	
	II	218	232	
	III	219	252	239
2, 9	I, 6	220	216	
	II	221	216	
	III	222	227	220
2, 10	I, 6	223	201	
	II	224	206	
	III	225	180	196
2, 11	I, 6	226	185	
	II	227	185	
	III	228	201	190
2, 12	I, 6	229	170	
	II	230	201	
	III	231	191	187
2, 1	I, 7	232	206	
	II	233	196	
	III	234	191	198
2, 2	I, 7	235	175	
	II	236	242	
	III	237	160	192
2, 3	I, 7	238	154	
	II	239	216	
	III	240	216	195
2, 4	I, 7	241	247	
	II	242	232	
	III	243	201	227

TABLE 4.—Continued

2, 5	I, 7	244	206	
	II	245	242	
	III	246	216	221
2, 6	I, 7	247	258	
	II	248	221	
	III	249	227	235
2, 7	I, 7	250	232	
	II	251	216	
	III	252	232	227
2, 8	I, 7	253	211	
	II	254	221	
	III	255	232	227
2, 9	I, 7	256	237	
	II	257	258	
	III	258	247	247
2, 10	I, 7	259	221	
	II	260	206	
	III	261	211	213
2, 11	I, 7	262	232	
	II	263	232	
	III	264	247	237
2, 12	I, 7	265	242	
	II	266	227	
	III	267	201	223
2, 1	I, 8	268	221	
	II	269	196	
	III	270	216	211
2, 2	I, 8	271	237	
	II	272	211	
	III	273	201	216
2, 3	I, 8	274	237	
	II	275	247	
	III	276	221	235
2, 4	I, 8	277	216	
	II	278	227	
	III	279	242	228
2, 5	I, 8	280	227	
	II	281	263	
	III	282	247	246
2, 6	I, 8	283	247	
	II	284	278	
	III	285	232	252
2, 7	I, 8	286	232	
	II	287	221	
	III	288	216	223
2, 8	I, 8	289	191	
	II	290	227	
	III	291	227	215
2, 9	I, 8	292	201	
	II	293	237	
	III	294	196	211
2, 10	I, 8	295	227	
	II	296	232	
	III	297	211	223
2, 11	I, 8	298	227	
	II	299	252	
	III	300	237	239
2, 12	I, 8	301	237	
	II	302	227	
	III	303	252	239
2, 1	I, 9	304	242	
	II	305	258	
	III	306	237	246
2, 2	I, 9	307	232	
	II	308	211	
	III	309	196	213
2, 3	I, 9	310	242	
	II	311	191	
	III	312	206	213
2, 4	I, 9	313	191	
	II	314	242	
	III	315	227	220
2, 5	I, 9	316	216	
	II	317	216	
	III	318	227	220
2, 6	I, 9	319	206	
	II	320	175	
	III	321	196	192
2, 7	I, 9	322	206	
	II	323	211	
	III	324	216	211
2, 8	I, 9	325	201	
	II	326	206	
	III	327	206	204
2, 9	I, 9	328	211	
	II	329	191	
	III	330	211	204
2, 10	I, 9	331	211	
	II	332	216	
	III	333	175	201
2, 11	I, 9	334	206	
	II	335	227	
	III	336	237	223
2, 12	I, 9	337	237	
	II	338	237	
	III	339	227	234
3, 1	I, 0	340	211	
	II	341	232	
	III	342	232	225
3, 2	I, 0	343	211	
	II	344	232	
	III	345	247	230
3, 3	I, 0	346	232	
	II	347	211	
	III	348	216	220
3, 4	I, 0	349	221	
	II	350	206	
	III	351	227	218
3, 5	I, 0	352	232	
	II	353	252	
	III	354	242	242
3, 6	I, 0	355	242	
	II	356	273	
	III	357	258	258
3, 7	I, 0	358	232	
	II	359	278	
	III	360	273	261
3, 8	I, 0	361	242	
	II	362	268	
	III	363	252	254
3, 9	I, 0	364	247	
	II	365	227	
	III	365	232	235
3, 10	I, 0	367	227	
	II	368	237	
	III	369	247	237
3, 11	I, 0	370	242	
	II	371	242	
	III	372	263	249
3, 12	I, 0	373	268	
	II	374	278	
	III	375	263	270
3, 1	I, 1	376	216	
	II	377	247	
	III	378	268	244
3, 2	I, 1	379	247	
	II	380	258	
	III	381	216	240
3, 3	I, 1	382	227	
	II	383	237	
	III	384	258	241
3, 4	I, 1	385	237	
	II	386	237	
	III	387	237	237
3, 5	I, 1	388	288	
	II	389	258	
	III	390	258	268
3, 6	I, 1	391	247	
	II	392	247	
	III	393	232	242
3, 7	I, 1	394	237	
	II	395	252	
	III	396	247	245
3, 8	I, 1	397	247	
	II	398	258	
	III	399	232	246
3, 9	I, 1	400	252	
	II	401	232	
	III	402	263	249
3, 10	I, 1	403	263	
	II	404	221	
	III	405	237	240
3, 11	I, 1	406	221	
	II	407	232	
	III	408	237	230
3, 12	I, 1	409	221	
	II	410	247	
	III	411	242	237
3, 1	I, 2	412	242	
	II	413	242	
	III	414	221	235
3, 2	I, 2	415	227	
	II	416	232	
	III	417	165	208
3, 3	I, 2	418	175	
	II	419	221	
	III	420	206	201
3, 4	I, 2	421	191	
	II	422	221	
	III	423	211	208
3, 5	I, 2	424	232	
	II	425	227	
	III	426	154	204
3, 6	I, 2	427	206	
	II	428	221	
	III	429	221	216
3, 7	I, 2	430	263	
	II	431	206	
	III	432	216	228
3, 8	I, 2	433	196	
	II	434	227	
	III	435	216	213
3, 9	I, 2	436	191	
	II	437	232	
	III	438	237	220
3, 10	I, 2	439	211	
	II	440	180	
	III	441	201	197
3, 11	I, 2	442	211	
	II	443	185	
	III	444	201	199
3, 12	I, 2	445	258	
	II	446	237	
	III	447	211	235
3, 1	I, 3	448	258	
	II	449	247	
	III	450	268	258
3, 2	I, 3	451	258	
	II	452	242	
	III	453	242	247
3, 3	I, 3	454	237	
	II	455	206	
	III	456	206	216
3, 4	I, 3	457	211	
	II	458	227	
	III	450	191	210
3, 5	I, 3	460	106	
	II	461	206	
	III	462	232	211
3, 6	I, 3	463	206	
	II	464	216	
	III	465	232	218
3, 7	I, 3	466	247	
	II	467	242	
	III	468	221	237
3, 8	I, 3	469	221	
	II	470	221	
	III	471	216	219
3, 9	I, 3	472	252	
	II	473	247	
	III	474	263	254
3, 10	I, 3	475	263	
	II	476	237	
	III	477	263	253
3, 11	I, 3	478	242	
	II	479	263	
	III	480	273	259
3, 12	I, 3	481	268	
	II	482	252	
	III	483	258	259
3, 1	I, 4	484	258	
	II	485	237	
	III	486	247	247

Table 4.—Continued

3, 2	I, 4	487	263	
	II	488	216	
	III	489	227	235
3, 3	I, 4	490	247	
	II	491	221	
	III	492	258	242
3, 4	I, 4	493	232	
	II	494	221	
	III	495	221	225
3, 5	I, 4	496	227	
	II	497	242	
	III	498	221	230
3, 6	I, 4	499	242	
	II	500	258	
	III	501	252	251
3, 7	I, 4	502	258	
	II	503	232	
	III	504	232	241
3, 8	I, 4	505	211	
	II	506	237	
	III	507	227	225
3, 9	I, 4	508	232	
	II	509	247	
	III	510	263	247
3, 10	I, 4	511	263	
	II	512	268	
	III	513	263	265
3, 11	I, 4	514	268	
	II	515	263	
	III	516	258	263
3, 12	I, 4	517	268	
	II	518	258	
	III	519	247	258
3, 1	I, 5	520	242	
	II	521	268	
	III	522	232	247
3, 2	I, 5	523	237	
	II	524	237	
	III	525	216	230
3, 3	I, 5	526	221	
	II	527	242	
	III	528	263	242
3, 4	I, 5	529	237	
	II	530	242	
	III	531	227	235
3, 5	I, 5	532	247	
	II	533	232	
	III	534	247	242
3, 6	I, 5	535	237	
	II	536	237	
	III	537	247	240
3, 7	I, 5	538	247	
	II	539	227	
	III	540	232	235
3, 8	I, 5	541	247	
	II	542	263	
	III	543	237	249
3, 9	I, 5	544	232	
	II	545	237	
	III	546	227	232
3, 10	I, 5	547	237	
	II	548	242	
	III	549	242	240
3, 11	I, 5	550	247	
	II	551	268	
	III	552	252	256
3, 12	I, 5	553	247	
	II	554	263	
	III	555	273	261
3, 1	I, 6	556	237	
	II	557	263	
	III	558	227	242
3, 2	I, 6	559	242	
	II	560	263	
	III	561	196	234
3, 3	I, 6	562	201	
	II	563	237	
	III	564	232	223
3, 4	I, 6	565	232	
	II	566	237	
	III	567	237	235
3, 5	I, 6	568	237	
	II	569	232	
	III	570	247	239
3, 6	I, 6	571	258	
	II	572	252	
	III	573	247	252
3, 7	I, 6	574	252	
	II	575	242	
	III	576	242	245
3, 8	I, 6	577	232	
	II	578	252	
	III	579	242	242
3, 9	I, 6	580	232	
	II	581	252	
	III	582	263	249
3, 10	I, 6	583	252	
	II	584	252	
	III	585	242	249
3, 11	I, 6	586	268	
	II	587	273	
	III	588	258	266
3, 12	I, 6	589	278	
	II	590	263	
	III	591	247	263
3, 1	I, 7	592	247	
	II	593	273	
	III	594	242	254
3, 2	I, 7	595	247	
	II	596	237	
	III	597	252	245
3, 3	I, 7	598	211	
	II	599	221	
	III	600	227	220
3, 4	I, 7	601	201	
	II	602	211	
	III	603	216	209
3, 5	I, 7	604	180	
	II	605	227	
	III	606	237	215
3, 6	I, 7	607	237	
	II	608	237	
	III	609	242	239
3, 7	I, 7	610	221	
	II	611	227	
	III	612	232	227
3, 8	I, 7	613	242	
	II	614	232	
	III	615	242	239
3, 9	I, 7	616	252	
	II	617	247	
	III	618	237	245
3, 10	I, 7	619	242	
	II	620	227	
	III	621	242	237
3, 11	I, 7	622	247	
	II	623	247	
	III	624	247	247
3, 12	I, 7	625	258	
	II	626	252	
	III	627	278	263
3, 1	I, 8	628	232	
	II	629	268	
	III	630	206	235
3, 2	I, 8	631	221	
	II	632	237	
	III	633	273	244
3, 3	I, 8	634	268	
	II	635	237	
	III	636	242	249
3, 4	I, 8	637	232	
	II	638	206	
	III	639	237	225
3, 5	I, 8	640	237	
	II	641	227	
	III	642	206	223
3, 6	I, 8	643	211	
	II	644	227	
	III	645	232	223
3, 7	I, 8	646	227	
	II	647	232	
	III	648	221	227
3, 8	I, 8	649	227	
	II	650	232	
	III	651	232	230
3, 9	I, 8	652	237	
	II	653	232	
	III	654	242	237
3, 10	I, 8	655	247	
	II	656	247	
	III	657	263	252
3, 11	I, 8	658	268	
	II	659	268	
	III	660	268	268
3, 12	I, 8	661	258	
	II	662	273	
	III	663	258	263
3, 1	I, 9	664	...	
	II	665	237	
	III	666	242	240
3, 2	I, 9	667	216	
	II	668	185	
	III	669	232	211
3, 3	I, 9	670	221	
	II	671	216	
	III	672	232	223
3, 4	I, 9	673	221	
	II	674	227	
	III	675	201	216
3, 5	I, 9	676	211	
	II	677	221	
	III	678	211	214
3, 6	I, 9	679	211	
	II	680	196	
	III	681	221	209
3, 7	I, 9	682	221	
	II	683	227	
	III	684	201	216
3, 8	I, 9	685	201	
	II	686	180	
	III	687	227	203
3, 9	I, 9	688	252	
	II	689	232	
	III	690	232	239
3, 10	I, 9	691	221	
	II	692	237	
	III	693	227	228
3, 11	I, 9	694	258	
	II	695	258	
	III	696	221	246
3, 12	I, 9	697	227	
	II	698	258	
	III	699	242	242
4, 1	I, 0	700	237	
	II	701	242	
	III	702	237	239
4, 2	I, 0	703	227	
	II	704	227	
	III	705	232	229
4, 3	I, 0	706	232	
	II	707	211	
	III	708	211	218
4, 4	I, 0	709	227	
	II	710	211	
	III	711	268	235
4, 5	I, 0	712	242	
	II	713	237	
	III	714	268	249
4, 6	I, 0	715	247	
	II	716	252	
	III	717	242	247
4, 7	I, 0	718	258	
	II	719	252	
	III	720	242	251
4, 8	I, 0	721	242	
	II	722	237	
	III	723	242	240
9	I	724	263	
	II	725	252	
	III	726	242	252
10	I	727	247	
	II	728	227	
	III	729	252	242

TABLE 4.—Continued

11	I	730	252	
	II	731	227	
	III	732	216	232
12	I	733	242	
	II	734	258	
	III	735	258	253
4, 1	I, 1	736	232	
	II	737	268	
	III	738	242	247
2	I	739	216	
	II	740	247	
	III	741	273	245
3	I	742	258	
	II	743	232	
	III	744	268	253
4	I	745	247	
	II	746	242	
	III	747	221	237
5	I	748	247	
	II	749	216	
	III	750	263	242
6	I	751	263	
	II	752	216	
	III	753	268	249
7	I	754	258	
	II	755	268	
	III	756	283	270
8	I	757	283	
	II	758	252	
	III	759	242	259
9	I	760	278	
	II	761	263	
	III	762	216	252
10	I	763	273	
	II	764	258	
	III	765	247	259
11	I	766	268	
	II	767	247	
	III	768	247	254
12	I	769	263	
	II	770	258	
	III	771	283	268
4, 1	I, 2	772	288	
	II	773	237	
	III	774	247	257
2	I	775	247	
	II	776	252	
	III	777	247	249
3	I	778	221	
	II	779	221	
	III	780	216	219
4	I	781	227	
	II	782	237	
	III	783	232	232
5	I	784	227	
	II	785	242	
	III	786	257	242
6	I	787	257	
	II	788	237	
	III	789	247	247
7	I	790	252	
	II	791	257	
	III	792	232	247
4, 8	I, 2	793	232	
	II	794	237	
	III	795	237	235
9	I	796	247	
	II	797	196	
	III	798	232	225
10	I	799	232	
	II	800	227	
	III	801	216	225
11	I	802	237	
	II	803	242	
	III	804	257	245
12	I	805	232	
	II	806	211	
	III	807	227	223
4, 1	I, 3	808	206	
	II	809	206	
	III	810	211	208
2	I	811	216	
	II	812	242	
	III	813	232	230
3	I	814	206	
	II	815	247	
	III	816	221	225
4	I	817	211	
	II	818	227	
	III	819	237	225
5	I	820	242	
	II	821	232	
	III	822	237	237
6	I	823	252	
	II	824	263	
	III	825	263	259
7	I	826	252	
	II	827	221	
	III	828	257	243
8	I	829	247	
	II	830	242	
	III	831	257	249
9	I	832	232	
	II	833	247	
	III	834	242	240
10	I	835	232	
	II	836	247	
	III	837	232	237
11	I	838	237	
	II	839	247	
	III	840	206	230
12	I	841	232	
	II	842	227	
	III	843	263	241
4, 1	I, 4	844	252	
	II	845	242	
	III	846	227	240
2	I	847	257	
	II	848	263	
	III	849	252	257
3	I	850	216	
	II	851	242	
	III	852	227	228
4	I	853	216	
	II	854	227	
	III	855	227	223
5	I	856	242	
	II	857	237	
	III	858	227	235
6	I	859	237	
	II	860	221	
	III	861	227	228
7	I	862	237	
	II	863	227	
	III	864	237	234
4, 8	I, 4	865	263	
	II	866	216	
	III	867	206	228
9	I	868	206	
	II	869	221	
	III	870	191	206
10	I	871	232	
	II	872	206	
	III	873	185	208
11	I	874	247	
	II	875	237	
	III	876	232	239
12	I	877	237	
	II	878	268	
	III	879	232	246
4, 1	I, 5	880	201	
	II	881	211	
	III	882	206	206
2	I	883	242	
	II	884	247	
	III	885	232	240
3	I	886	232	
	II	887	232	
	III	888	206	223
4	I	889	232	
	II	890	253	
	III	891	247	244
5	I	892	237	
	II	893	237	
	III	894	242	239
6	I	895	232	
	II	896	227	
	III	897	227	229
7	I	898	258	
	II	899	242	
	III	900	242	247
8	I	901	247	
	II	902	232	
	III	903	221	233
9	I	904	232	
	II	905	216	
	III	906	211	220
10	I	907	232	
	II	908	221	
	III	909	206	220
11	I	910	258	
	II	911	242	
	III	912	252	251
12	I	913	221	
	II	914	216	
	III	915	216	218
4, 1	I, 6	916	221	
	II	917	227	
	III	918	258	235
2	I	919	211	
	II	920	201	
	III	921	201	204
3	I	922	191	
	II	923	185	
	III	924	206	194
4	I	925	252	
	II	926	242	
	III	927	211	235
5	I	928	252	
	II	929	252	
	III	930	227	244
6	I	931	258	
	II	932	247	
	III	933	258	254
7	I	934	237	
	II	935	258	
	III	936	221	239
4, 8	I, 6	937	221	
	II	938	216	
	III	939	252	230
9	I	940	252	
	II	941	232	
	III	942	221	235
10	I	943	216	
	II	944	232	
	III	945	237	228
11	I	946	247	
	II	947	258	
	III	948	263	256
12	I	949	304(?)	
	II	950	273(?)	
	III	951	221(?)	266
4, 1	I, 7	952	278	
	II	953	258	
	III	954	258	265
2	I	955	216(?)	
	II	956	237	
	III	957	242	232
3	I	958	185	
	II	959	206	
	III	960	216	202
4	I	961	191	
	II	962	227	
	III	963	232	217
5	I	964	232	
	II	965	232	
	III	966	216	227
6	I	967	211	
	II	968	247	
	III	969	242	233
7	I	970	237	
	II	971	232	
	III	972	211	227

Table 4.—Concluded

8	I	973	216	
	II	979	221	
	III	975	252	230
9	I	976	221	
	II	977	237	
	III	978	221	226
10	I	979	227	
	II	980	237	
	III	981	263	242
11	I	982	273	
	II	983	242	
	III	984	247	254
12	I	985	258	
	II	986	237	
	III	987	263	253
4, 1	I, 8	988	278	
	II	989	247	
	III	990	263	263
2	I	991	273	
	II	992	268	
	III	993	258	266
3	I	994	278	
	II	995	247	
	III	996	247	257
4	I	997	293(?)	
	II	998	252	
	III	999	258	268
5	I	1000	258	
	II	1001	252	
	III	1002	263	258
6	I	1003	283	
	II	1004	273	
	III	1005	273	276
7	I	1006	299	
	II	1007	288	
	III	1008	283	290
4, 8	I, 8	1009	283	
	II	1010	278	
	III	1011	237	266
9	I	1012	252	
	II	1013	278	
	III	1014	278	269
10	I	1015	258	
	II	1016	258	
	III	1017	253	356
11	I	1018	278	
	II	1019	268	
	III	1020	283	276
12	I	1021	278	
	II	1022	283	
	III	1023	278	280
4, 1	I, 9	1024	278	
	II	1025	247	
	III	1026	273	266
2	I	1027	304	
	II	1028	294	
	III	1029	232	278
3	I	1030	242	
	II	1031	252	
	III	1032	206	233
4	I	1033	221	
	II	1034	206	
	III	1035	258	228
5	I	1036	242	
	II	1037	273	
	III	1038	242	252
6	I	1039	232	
	II	1040	191	
	III	1041	242	222
7	I	1042	237	
	II	1043	242	
	III	1044	247	242
8	I	1045	242	
	II	1046	263	
	III	1047	221	242
9	I	1048	227	
	II	1049	237	
	III	1050	206	223
10	I	1051	232	
	II	1052	221	
	III	1053	263	239
11	I	1054	268	
	II	1055	247	
	III	1056	237	251
12	I	1057	263	
	II	1058	242	
	III	1059	288	264
5, 1	I, 0	1060	288	
	II	1061	268	
	III	1062	268	275
2	I	1063	227	
	II	1064	237	
	III	1065	247	237
3	I	1066	227	
	II	1067	227	
	III	1068	211	222
4	I	1069	221	
	II	1070	211	
	III	1071	206	213
5	I	1072	232	
	II	1073	206	
	III	1074	247	228
6	I	1075	242	
	II	1076	232	
	III	1077	247	240
7	I	1078	211	
	II	1079	242	
	III	1080	232	228
5, 8	I, 0	1081	253	
	II	1082	253	
	III	1083	216	241
9	I	1084	206	
	II	1085	237	
	III	1086	237	227
10	I	1087	243	
	II	1088	249	
	III	1089	283	258
11	I	1090	263	
	II	1091	227	
	III	1092	252	247
12	I	1093	232	
	II	1094	247	
	III	1095	227	235

1.9 to 2.0 calories, or even more. Still, by forming these less-accurate solar-constant values into large groups of days, according to magnitude, H. H. Clayton was able to correlate solar changes with weather elements.[9]

It now occurs to me that since the periodicities now discovered in the solar emission have been expressed as to form and amplitude, and since 1920 seem to be permanent as far as known in period, amplitude, and form, it may be worth while to synthesize monthly mean solar variation *backward* from 1920. This done, it would be possible to compare the values synthesized with monthly mean solar-constant values observed on Mount Wilson. If, on the whole, high, medium, and low solar constants as synthesized correspond to high, medium, and low Mount Wilson values, it will be a confirmatory evidence of the sun's real variability, of the constancy of periodicities, of their comprising nearly the total solar variation, and of the value of Clayton's work on the correlation of solar variation with weather.

Table 5 gives the synthesized monthly solar-constant values from

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[9] Smithsonian Misc. Coll., vol. 68, No. 3, 1917.

August 1908 to December 1920. These results are given graphically in figure 5,C. These are actual estimated solar constants in calories per square centimeter per minute, not, as in table 4, percentage departures from 1.90 calories.

COMPARISON OF SYNTHETIC WITH MOUNT WILSON SOLAR-CONSTANT VALUES

From table 53, page 193, volume 4, Annals of the Astrophysical Observatory, I take monthly solar-constant values determined from Mount Wilson observations in the months May to November, 1908 to 1920. I omit four values, July and August 1912, because the sky was then very much fouled by dust from the volcano, Mount Katmai.[10] I also omit July values of 1910 and 1917 because they are very wild indeed, far beyond the limits of dispersal of the others.

Having plotted the Mount Wilson values and such parts of the synthetic series as corresponded in time with them, I saw that there was a gradual rise in values in both observed and synthetic series from 1908 to 1914. I drew straight lines best following this trend to represent the means of the values over that interval, and read off the departures of the individual solar-constant values on the plot from these lines. For the rest of the total interval, that is 1915 to 1920, I read departures from straight horizontal lines drawn in the mean of ordinates. The plot was in arbitrary units, with the units for ordinates in the synthetic plot twice as large as those for the Mount Wilson data. These departure values follow in table 6.

Taking the sums of the data in the columns of table 6 they yield: Mount Wilson $\div$ synthetic $= \frac{503}{284} = 1.77$. Recalling the ratio of units, 2 to 1, it appears that the dispersal of Mount Wilson data is 3.54 times as great as that of the synthetic data. The synthetic curve 1920-1950, however, as plotted in figure 4, shows practically the same range of variation as does the curve of original modern observations. Hence it appears that the Mount Wilson solar-constant observations of 1908 to 1920 are probably $3\frac{1}{2}$ times less accurate than the modern work set forth in table 4.

Taking account of the numbers of departures of the same sign in the columns of table 6, and the numbers of them of opposite signs, the sums are 28 and 21.

Taking the sums of departures that are of the same sign in both columns, the results are 324 for Mount Wilson and 170 for the syn-

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[10] See Smithsonian Misc. Coll., vol. 60, No. 29, 1913.

TABLE 5.—*Synthesized solar constant, 1908-1920*

Values to be prefixed by 1.9

1908	Aug.	49	1912	Jan.	45	1915	Jan.	45	1918	Jan.	47
	Sept.	49		Feb.	46		Feb.	50		Feb.	46
	Oct.	48		Mar.	48		Mar.	48		Mar.	43
	Nov.	46		Apr.	45		Apr.	51		Apr.	44
	Dec.	45		May	46		May	48		May	43
1909	Jan.	45		June	45		June	45		June	46
	Feb.	44		July	43		July	42		July	45
	Mar.	43		Aug.	44		Aug.	38		Aug.	46
	Apr.	40		Sept.	42		Sept.	40		Sept.	47
	May	39		Oct.	44		Oct.	42		Oct.	48
	June	39		Nov.	47		Nov.	43		Nov.	50
	July	42		Dec.	46		Dec.	45		Dec.	51
	Aug.	43	1913	Jan.	45	1916	Jan.	43	1919	Jan.	52
	Sept.	42		Feb.	47		Feb.	51		Feb.	49
	Oct.	45		Mar.	46		Mar.	53		Mar.	46
	Nov.	42		Apr.	48		Apr.	52		Apr.	47
	Dec.	40		May	45		May	47		May	48
1910	Jan.	40		June	46		June	42		June	46
	Feb.	41		July	47		July	40		July	44
	Mar.	43		Aug.	49		Aug.	36		Aug.	44
	Apr.	49		Sept.	48		Sept.	39		Sept.	48
	May	47		Oct.	46		Oct.	43		Oct.	47
	June	47		Nov.	45		Nov.	42		Nov.	44
	July	46		Dec.	43		Dec.	44		Dec.	41
	Aug.	47	1914	Jan.	46	1917	Jan.	43	1920	Jan.	43
	Sept.	46		Feb.	48		Feb.	44		Feb.	46
	Oct.	46		Mar.	48		Mar.	47		Mar.	45
	Nov.	44		Apr.	52		Apr.	46		Apr.	42
	Dec.	42		May	51		May	44		May	44
1911	Jan.	45		June	44		June	44		June	43
	Feb.	45		July	40		July	42		July	42
	Mar.	46		Aug.	41		Aug.	44		Aug.	41
	Apr.	48		Sept.	41		Sept.	43		Sept.	42
	May	52		Oct.	41		Oct.	46		Oct.	48
	June	48		Nov.	41		Nov.	50		Nov.	48
	July	47		Dec.	43		Dec.	48		Dec.	46
	Aug.	46									
	Sept.	45									
	Oct.	44									
	Nov.	40									
	Dec.	41									

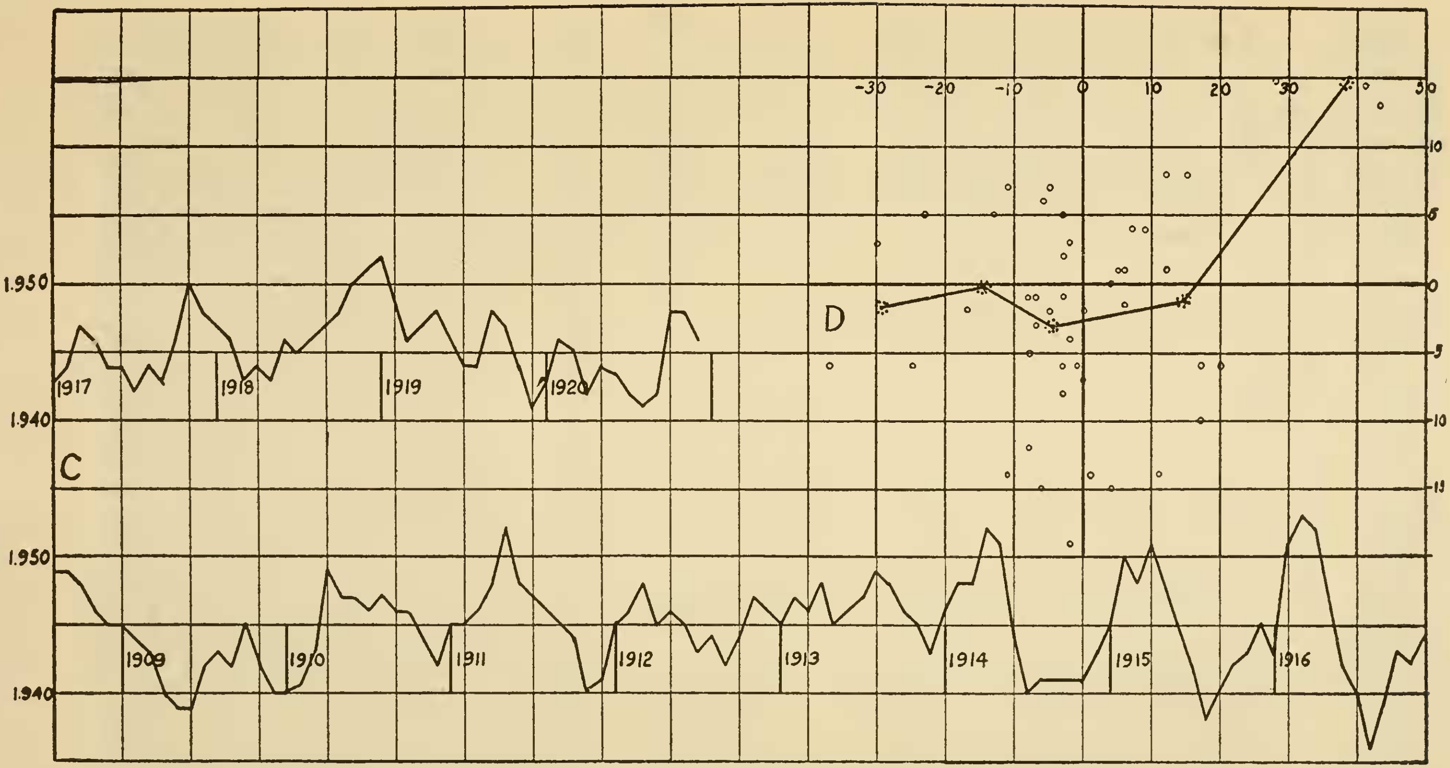

FIG. 5.—C, Solar-constant values in calories, as synthesized from 23 periodicities, 1908 to 1920. D, A comparison of mean monthly solar-constant departures from the mean, Mount Wilson (abscissae) vs. synthetic (ordinates).

thetic data. The corresponding sums for departures of opposite signs are 199 and 135. Thus, according to Mount Wilson, agreeing departures preponderate in total magnitude over disagreeing departures as $\frac{324}{199} = 1.6$. Similarly, for synthetic values the results are $\frac{170}{135} = 1.3$.

Table 6.—*Comparison of Mount Wilson and synthetic values*

	Mount Wilson	Syn.		Mount Wilson	Syn.		Mount Wilson	Syn.
1908			*1912*			*1916*		
Aug.	+45	+16	May	+ 5	+ 1	June	− 1	− 6
Sept.	+28	+15	June	− 8	− 1	July	− 3	−10
Oct.	+43	+13	*1913*			Aug.	+ 2	−18
1909			Aug.	− 7	+ 5	Sept.	− 8	−12
June	+17	− 6	Sept.	−30	+ 3	*1917*		
July	− 3	− 1	*1914*			July	+20	− 6
Aug	+12	+ 1	June	± 0	− 7	Aug.	+ 6	− 2
Sept.	− 7	− 1	July	+ 4	−15	Sept.	− 2	− 4
1910			Aug.	+11	−14	*1918*		
May	+12	+ 8	Sept.	−11	−14	June	− 7	+ 2
June	− 5	+ 7	Oct.	− 6	−15	July	+ 4	± 0
July	−24	+ 5	*1915*			Aug.	− 3	+ 2
Aug.	−11	+ 7	June	− 8	± 0	Sept.	+ 9	+ 4
Sept.	−13	+ 5	July	− 3	− 6	*1919*		
Oct.	+ 3	+ 5	Sept.	+ 1	−14	June	+ 7	+ 4
1911			Oct.	+17	−10	July	± 0	− 2
June	+15	+ 8				Aug.	− 5	− 2
July	−13	+ 5				Sept.	− 6	+ 6
Aug.	− 2	+ 3				*1920*		
Sept.	+ 6	+ 1				July	−25	− 6
Oct.	−17	− 2				Aug.	− 3	− 8
						Sept.	−37	− 6

Finally, I show in figure 5,D, the Mount Wilson departures as abscissae against the synthetic departures as ordinates. The plotted points are greatly scattered, as the inaccuracy of Mount Wilson solar-constant values would lead us to expect. Yet, on the whole, the comparison indicates that high departures tend to occur simultaneously in both sets of data, and low departures similarly.

Thus four kinds of rough indications agree to confirm the view that the synthetic solar-constant values of 1908 to 1920 are supported as to their validity, at least in some degree, by the evidences from Mount Wilson observations. The four evidences are: 1. Both sets of data yield upward trends from 1908 to 1914. 2. Departures from representative lines have the same signs 28 times, opposite signs, 21.

3. The summation of departures of the same sign exceeds that for those of opposite sign about 1½ times. 4. The plot of departures indicates a positive correlation between Mount Wilson and synthetic solar-constant values.

The great inferiority in accuracy of Mount Wilson values of the solar constant forbids a high degree of correlation, even if the synthetic values are as correct from 1908 to 1920 as they are from 1920 to 1950. This inferiority arises from the fact that all the Mount Wilson values result from observations by the "long method." That method requires for accuracy a sky of constant transparency over several hours. If the sky improves, the solar-constant value is too high, and vice versa. Moreover, only one value was obtained per day with the "long method." In modern solar-constant work by the "short method," several values are obtained and combined on each day of observation. The sky is required to retain uniform transparency only during about 10 minutes of each observation. It might vary decidedly from one determination to another of the day's group, and yet all the solar-constant values of the day be closely agreeing.

SOLAR CONSTANT AND SOLAR CONTRAST

The Mount Wilson work offers another test of the probable validity of the synthetic solar-constant curve of 1908 to 1920. From 1913 to 1920 we were accustomed to produce drift energy curves in several wavelengths, observing intensities along the east-west diameter of an 8-inch solar image, on every day that we observed the solar constant of radiation. These U-shaped curves, which show the contrast in brightness between the center and edges of the sun's disk, were all measured as described in volume 4 of the Annals of the Smithsonian Astrophysical Observatory. We used an empirical formula to obtain a value to represent the average contrast between center and edge of the sun's disk on each day of observation. These data are given in tables 75 to 82 of volume 4 of the Annals.

It was thought probable that the "solar contrast" would be greater on days when the "solar constant" was higher. Some figures, indicating that this is so, are given in volumes 3 and 4 of the Annals.

Table 7, which follows here, is prepared from the "solar contrast" tables of the Annals, volume 4, and from table 6, just given, which presents synthetic solar-constant values of 1908 to 1920. To prepare the solar-contrast values for this use, means of the daily values are taken of every month given in Annals 4. Then, in order to eliminate systematic errors which might introduce inconsistencies, a separate mean value is computed for the available months of each year, 1913 to 1920. Differences from these yearly means are given in column 2 of table 7. To make the synthetic solar-constant values entirely comparable to these contrast values, separate means of them are taken for each year of the comparison, including only the months used in obtaining the separate contrast means. Differences from these synthetic solar-constant means, expressed in thousandths of a calorie, form column 1 of table 7.

TABLE 7.—*Comparison of synthetic solar-constant departures with solar-contrast values of 1913-1920*

Solar-constant departures in thousandths of a calorie.

Solar constant	Solar contrast
+17	+19
— 3	—32
—13	+14
+36	—35
+ 6	—24
—34	—18
—14	+28
+ 6	+49
+20	+10
0	—29
—40	—75
—10	0
+30	+ 4
—17	—18
+ 3	+15
— 7	+14
—14	—23
— 4	—12
+ 6	+ 8
+16	+16
+ 5	— 8
—15	—13
—15	+13
+25	+40
+ 3	+46
— 7	+18
+ 3	—70
+23	—13
— 4	+ 9

Counting the numbers of months when values in columns 1 and 2 have the same sign and opposite signs, the numbers (counting zero values into each group) are 18 and 13, respectively. So here is another straw pointing to the reliability of the synthetic solar-constant values. But more convincing, and more informing, is figure 6. Here the values in the columns of table 7 are plotted against each other, solar constants as ordinates, solar contrasts as abscissae. In order to bring out plainly the fact that higher contrast values attend higher synthetic solar-constant values, stars 1, 2, 3, 4, 5, have been plotted to give the centers of gravity of groups of 8, 8, 5, 5, and 2 months, respectively. A full heavy line has been drawn to show the trend of the results.

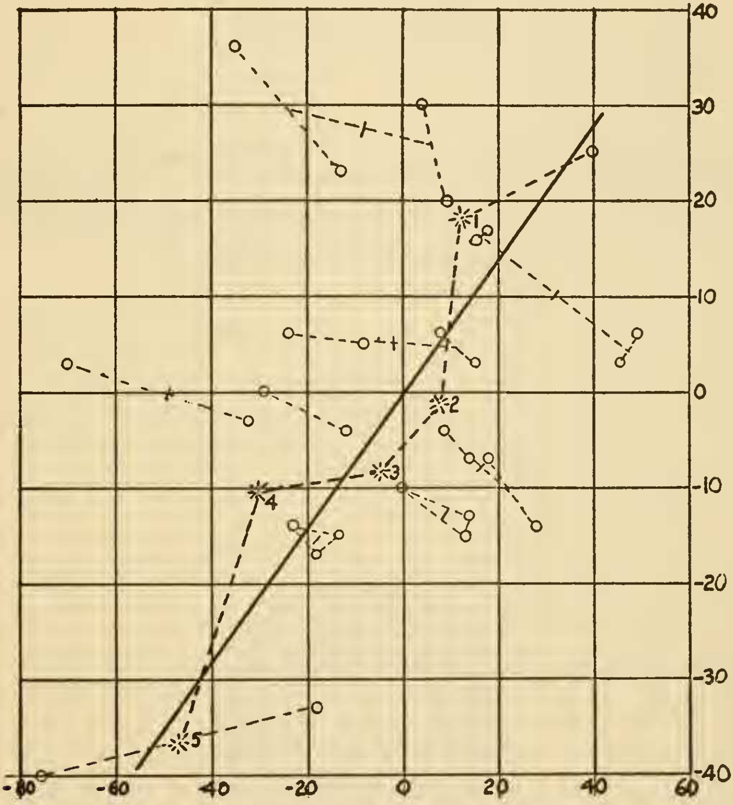

FIG. 6.—Mount Wilson solar contrast (abscissae) vs. synthetic solar constants (ordinates).